Independent behavioral experiments on rats and primates had revealed that thresholds of *behavioral incapacitation* occurred during exposures of a few tens of minutes when microwave or shortwave irradiation resulted in whole-body-averaged SARs near 4 W/kg. Although reversible when durations of exposure are short--less than one hour--behavioral incapacitation was adopted by ANSI as its most reliable end point for indexing harmful levels of RF radiation. To insure a margin of safety, a tenfold reduction from the SAR threshold of harm to an SAR of 0.4 W/kg was adopted for limiting exposure of human populations.

Capture of RF energy is maximal at whole-body resonance, which will occur in human beings at frequencies that range from approximately 30 MHz (tall adult) to 300 MHz (short infant). Any given individual has two modes of whole-body resonance, one mode based on an ungrounded body, and one on grounding, which effectively doubles the body's wavelength and halves its resonant frequency. To limit the SAR to 0.4 W/kg within the range of resonant frequencies, the power density of incident radiation must not exceed 10 W/m^2. At frequencies below 30 MHz and above 300 MHz, power-density limits are relaxed.

PROGRESS (?) ON A NEW ANSI STANDARD

Although ANSI policy mandates a decision on its standards at five-year intervals--reaffirm, revise, or reject--the promulgation of a standard in 1987 did not materialize. And it is unlikely that one will materialize in calendar year 1988. Several factors are responsible for the delay, each of which deserves examination.

Unwieldy Evaluative Procedures

In evaluating the biomedical literature on RF radiations in the period before adoption of the 1982 standard, members of Subcommittee C95-IV utilized a narrow-but-focused sample of pertinent reports. The criteria for acceptance of a report were a) concurrence by physical, engineering, medical, and life scientists that the report's data are based on technically and scientifically sound procedures; b) the report must contain experimental findings of an SAR threshold of putative harm in a mammalian species; and c) other reports must provide independent confirmation of the threshold of harm in the same or another species. Because of the relatively small number of reports that met criteria--only a few dozen among a data base of thousands--Subcommittee C95-IV came under intense criticism after publication of the 1982 standard.

To counter such criticism in a revised standard, a decision was made to perform a large-scale evaluation of data, virtually all that had been reported in the archival literature between 1982 and 1985. Two committees were formed to provide a first-pass round of evaluations, Physical Principles Validation and Biological Principles Validation, which were chaired, respectively, by Prof. Arthur W. Guy of the University of Washington (Seattle) and by me. As is their wont, the engineers and physicists of Prof. Guy's committee responded admirably to their charge: to determine which of 300-plus archival reports contain reliable data on SAR thresholds. I suggested that my committee await the findings of Prof. Guy's committee--why burden biological scientists with reports that can't pass dosimetric muster?--but was overruled. A massive mailing to chairmen of select working groups ensued. Unfortunately, my concern that the burden would eventuate in prolonged delays in completion of evaluations was confirmed.

Biological experiments, in virtue of methodological nuance and subject-matter complexity, can sorely tax the time of scientists that are attempting to read reports and reach interpretive consensus. If my reading of the box score is accurate, somewhere between one-third and one-half the reports failed to get a passing grade from Prof. Guy's committee. Demoralizing, then, were after-the-fact discoveries that reports, on each of which one had spent one or two hours, had been declared null and void by the physical scientists. Hindsight also dictates another argument against large-scale evaluations: Why include reports, however valid and virtuous, that are based on high levels of energy dosing? An experiment in which rats were decimated by radiation at 40 W/kg has doubtful implications for a standard that has limited the SAR at 0.4 W/kg.

As a footnote with implications for timeliness of future ANSI revisions, I suggest anew that dosimetric evaluations precede biological review. Screening of reports to winnow those irrelevant to exposure standards would also reduce the workload and accelerate the evaluative pace.

The original intent, once the Physical and Biological Principles Committees completed their work, was to forward recommendations to a Risk Evaluation Committee--or, if statistical problems were evident, to a special committee that would address questions of data analysis. At the time this paragraph was written (June of 1988), the Risk Evaluation Committee had not issued a report of its activities, which may indicate that its task is yet to be completed.

Indemnification

Citizens of the United States justly enjoy a reputation for being litigious. Although the threat of legal action against any given ANSI committee or subcommittee might be low in probability, the existence of hundreds of standards that bear on the public's health constitutes a valid economic concern. Consequently, the administrators of ANSI have backed away from bonding or insuring the volunteers that generate and sanction its standards. The possibility that one might stand naked in the adversarial courtyard has understandably chilled the enthusiasm that members of Subcommittee C95-IV have brought to their standard-setting endeavours. Even if all the evaluative committees had completed grading of all papers in the bioelectromagnetics literature, and even if the Risk Evaluation Committee had issued final guidance, a new ANSI standard would not be forthcoming until indemnification of individual participants had been achieved. To this end, Prof. Arthur Guy and the Secretary of Subcommittee C95-IV, Dr. John Osepchuk of the Raytheon Company, have devoted much effort. They have been aided by the Committee on Man and Radiation (COMAR) and by the Technical Activities Council (TAC) of the Institute of Electrical and Electronic Engineers (IEEE). A former co-sponsor of ANSI Committee C95 with the Department of the Navy, the IEEE has been invited to become the Committee's sole sponsor. In this capacity, the IEEE would provide legal protection of Committee and Subcommittee members.

On the Shedding of a Tier

ANSI Standard C95.1-1982 contains what many public-health professionals consider a paradox. The standard applies to civil as well as working populations, but no distinction is made with respect to recommended limits on exposure to RF radiations. Traditionally, public-health specialists inveigh more restrictive limits for members of civil populations than they do for workers in so-called controlled environments. Workers are doubtless healthier than older, more sickly members of the general population, and they may also be more aware of hazards in the working environment and means to mitigate them. These and other arguments have been waged in efforts to generate a two-tiered standard, one that would have less stringent limits for working populations. The counter argument is that an ANSI SAR limit, if "safe" for workers, could hardly be "safer" if made more stringent for the general population. Sentiments for and against a second tier are about evenly split among members of Subcommittee C95-IV. Because ANSI policy requires a substantial consensus on limits and guidance among its volunteering specialists, the division of opinion on a one- vs. two-tiered policy constitutes a troublesome obstacle in the elaboration of a revised standard.

What is the Hazard Threshold?

Two of the major entities with missions that entail development of RF standards--the NCRP and the U.S. Environmental Protection Agency (EPA)--published lengthy reviews of the bioelectromagnetics literature[1,2] after promulgation of ANSI C95.1-1982. In both reviews, the critical end point of behavioral incapacitation, which defines ANSI's 4-W/kg threshold of harm, was reaffirmed. Recently, however, in reporting an updated evaluation of the literature, the EPA has sounded a more conservative note:

> [I]t is concluded that exposure to RF radiation causes biological effects at SARs above and below 1 W/kg; some of the effects [that] occur at about 1 W/kg may be significant under certain environmental conditions. The biological significance of the effects [that] occur below 1 W/kg, including those. . .at specific temperatures different from the physiological temperature range, specific frequencies or at specific amplitude-modulation conditions is not established.[4]

The reference to "effects" that are "significant" circa 1 W/kg are based on a thermal-insult model in which in-house data from murine experiments were extrapolated to higher species, including man. This largely analytical model, which does not account for differing thermophysiological capabilities among the species, has not been validated in independent experimentation. Although Subcommittee C95-IV has yet to implement a lower SAR threshold of harm in consequence of the EPA's advice, any such move would subvert the 1982 criteria, which mandated use of independently verified experimental data. Caveat!

There are data that have created justifiable concern that the 4-W/kg threshold of harm may need to be revised downward. Reference is, first, to studies of mice in Poland by Szmigielski and colleagues[5] in which three different types of experimental malignancies were *promoted*--but not induced--by long-term, but intermittent, microwave irradiation at SARs near 2 W/kg. Second, I refer to the celebrated, but-yet-to-be-archival report of experiments on rats by Prof. Arthur W. Guy and colleagues at the University of Washington[6]. These experiments, which subjected animals to near life-long exposures to microwaves, revealed that SARs circa 0.4 W/kg were associated with a reliable increase of malignancies above control incidence. Remarkably, despite a nearly fourfold greater incidence of malignant tumors in exposed animals as compared with controls, average life spans did not differ. These data and those from the study performed in Poland have not been independently confirmed. The putative threshold of hazardous irradiation would doubtless be driven lower if either set of malignancy data met the critical scientific test of confirmation. It is ironic, to say the least, that levels of funding of research on microwaves and other high-frequency RF radiations have decreased so dramatically that attempts to confirm the malignancy studies may never be undertaken. The dilemma for participants in the standard-setting process is obvious: One should not use unconfirmed findings; but one is justifiably uneasy when well-executed experiments generate a portent of malignant disease.

Burns and Shocks

Profs. Om Gandhi and Arthur Guy have both confirmed in the laboratory what long ago a health physicist with the E.P.A., Richard Tell, learned by direct experience when climbing highly powered, low-frequency antennas. The lesson is that electric shocks and RF burns can be induced in the human body at relatively low power densities. The reader familiar with the "U" shaped power-density and field-strength curves that characterize ANSI Standard C95.1-1982 should be prepared to see some downward revision of limits, especially those at the lower end of the spectrum.

CONCLUDING SUMMARY

Six years have passed since publication of the current ANSI standard for protection of human populations from excessive RF radiations. Much work on a revised standard has been performed by evaluative committees and working groups, which have attempted, with mixed results, to perform a highly ambitious review of the bioelectromagnetics literature. There are other barriers that have delayed completion of a new standard, not the least of which has been disagreement by evaluators on whether to establish different limits on exposure of general and working populations. Perhaps the most foreboding barrier to completion of a new standard--one that reliably reflects the reality of field body interactions and that validly protects the human population--is the decline of support for scientific inquiry. Trite but true: A protective standard is no better than its data base.

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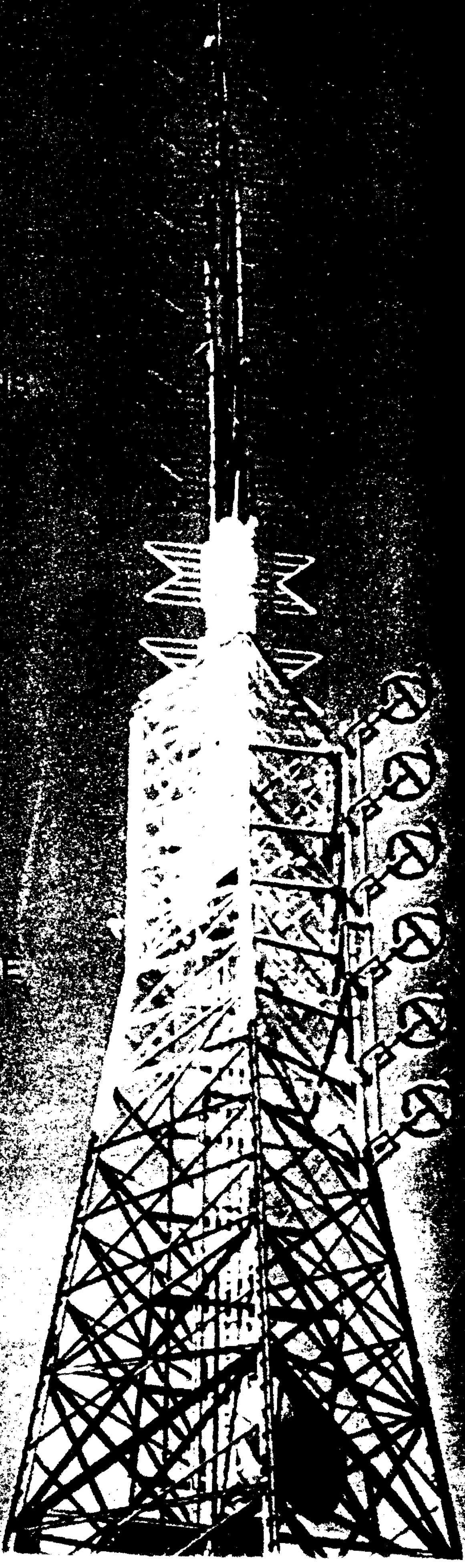

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REVIEW OF SELECTED REPORTS ON THE BIOLOGICAL RESPONSE TO RF FIELDS

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REVIEW OF SELECTED REPORTS ON THE BIOLOGICAL RESPONSE TO RF FIELDS

Prefatory Notes

The analysis and discussion of data in this review are based primarily on 20 publications that were selected by the Office of Long Range Planning, City of Seattle. The 20 publications are a subset of the literature on biological effects of exposure to microwaves, shortwaves, and other radio-frequency electromagnetic (RF) fields. The contents of the 20 reports are focused on health effects, especially those involving malignancies.

To provide the lay person a better grasp of the subject matter and techniques by which biological scientists evaluate a body of data, several topics of pertinence are addressed synoptically before discussion of the reports: mechanisms of interaction, dosimetry, thresholds, and statistically aided decisions.

Mechanisms

Broadly speaking, the influences of RF fields are categorized as thermal and athermal. Through conductive and dielectric "loss," RF energy is converted to thermal energy when the former is absorbed by tissues. A dangerous elevation of temperature will occur in a body if the energy absorbed from an incident field is of sufficient intensity and duration. Athermal effects embrace both the well-established phenomenon of electric shock, which can occur at relatively high field intensities, and other, ill-understood effects that can occur at relatively low intensities. Electric shocks are definitely hazardous. Whether other athermal effects pose a hazard is a highly controversial and unresolved question that has prompted much concern by scientists and lay persons alike. Complicating the interpretation of experimental findings is the possibility that both thermal and athermal interactions may take place simultaneously.

Field Densities and Dosimetry

The intensity of an RF field that is moving through free space is usually measured by its *power density,* which is the rate at which energy flows though a defined area. The measure of the rate at which energy is flowing is the *watt (W)*, and the measure of the area is usually the *square centimeter* (cm^2). Power density may therefore be defined as watts per square centimeter (W/cm^2). RF energy travelling through space at the rate of 1 W/cm^2 represents a highly intense field. It is equivalent to 1,000,000 *microwatts* per square centimeter ($\mu W/cm^2$). Power densities based on micro-watts will be used throughout this review.

The amount of energy absorbed by a body in a RF field during a given period of time is labelled *Specific Absorption (SA),* and it is defined in terms of body mass. The basic unit of energy is the *joule*, the basic unit of mass is the *kilogram*, and the dose or SA of RF energy is expressed simply as joules per kilogram (J/kg). Most U.S. standards are based on the *time-rate* derivative of SA, in which the *watt (W)*, which is defined as joules absorbed per second, is normalized to body mass, resulting in a dose rate labelled the *Specific Absorption Rate (SAR)*. Accordingly, the SAR is defined as *watts per kilogram (W/kg)*.

The reader may inquire why two time-rate measures, power density and the SAR, are necessary in interpreting biological effects of RF radiations. The answer is twofold: 1) the SAR is a better predictor of biological thresholds, which is explained by the fact that 2) bodies of human beings or subhuman animals differ greatly in dimensions, mass, and volume, and the amount of energy absorbed from an RF field is highly frequency specific. That is, radiation at the same power density but at different frequencies results in widely varying SARs. The frequencies at which human beings exhibit the highest SARs occur between 30 and 300 megahertz (MHz), in which are found, incidentally, the radiations associated with commercial FM broadcasts.

Thresholds of Biological Effects

The purpose of a radiation standard is to protect exposed persons from harm. It is therefore of importance to determine thresholds at which harmful effects occur. The first RF standard to invoke an SAR threshold of harm was that of the American National Standards Institute (ANSI C95.1-1982). Based on experimental studies of rodents and monkeys, it was found by several independent investigators that SARs near 4 W/kg during 20- to 60-minute exposures to microwave fields resulted in highly reliable evidence of *behavioral incapacitation*. Although the animals recovered from this loss of ability to perform, it was agreed by the members of the ANSI committee that any agent that disrupts performance places the organism at risk. Accordingly, 4 W/kg was accepted as the threshold of harm, and the highest permissible SAR was set at 0.4 W/kg to provide a margin of safety. Subsequently, the Environmental Protection Agency (EPA) and the National Council on Radiation Protection and Measurements (NCRP) have embraced behavioral incapacitation and an SAR of 4 W/kg as, respectively, the defining operation of harm and the threshold of harm. The NCRP has accepted the tenfold reduction of the SAR to 0.4 W/kg as the upper limit for occupational exposures to RF fields, but has also recommended a further reduction to 0.08 W/kg as a limit for the general population. The EPA has yet to recommend specific limits but is entertaining three SAR options in the formulation of a general-population standard: acceptance of the ANSI standard (0.4 W/kg), reduction to 0.08 W.kg, or reduction to 0.04 W/kg.

Statistical Decision-Making

Authors of most reports rely on statistical analyses to estimate the reliability of their findings. It is stressed that no statistical test "proves" that a causal relation exists or does not exist between exposure to an RF field and an adverse effect on health. Rather, all tests are estimates of the *probability (P)* that some difference or correlation occurs *by chance.* For example, a *P* value equal to .05 ($P = .05$) indicates that the odds are only 1 in 20 that a difference or correlation occurred "by chance." Similarly, given a *P* value less than .01 ($P < .01$), the probability of a chance (null) finding is less than 1 in 100. The statistical test does not "tell" the investigator whether a finding is real or spurious; the choice requires a decision that rests on human judgment. For most investigators, *P* values equal to or less than .05 define the limit for rejecting the null hypothesis.

Review

Introduction

Twelve of the 20 publications reviewed in this report are based on epidemiological studies. These are studies in which populations of human beings were examined for evidence of health problems in consequence of exposure to electric and magnetic fields in home or occupational settings. Five publications are based on *in-vivo* laboratory experiments, i.e., on intact, live, subhuman mammals. And three publications are based on experiments involving *in-vitro* preparations; that is, on biological materials removed from living animals. The results reported in each paper are summarized below. A general discussion, conclusions, and recommendations follow the reviews.

Epidemiological studies

Robinette C.D., Silverman, C., and Jablon, S. (1980). Effects upon health of occupational exposure to microwave radiation (Radar). *Amer. J. Epidem., 112:* 39-53. [E-1]

Data on U.S. Naval personnel that served during the Korean War were analyzed for evidence of an association between microwave exposure and negative impact on health. The personnel were classified under two categories: A minimal, potential-exposure group (which included radiomen, radarmen, and aviation electrician's mates; N = 20,781) and a high, potential-exposure group (which included electronic technicians, fire-control technicians, and aviation electronic technicians; N = 20,109). Exposure histories of individuals were not known. Exposure was indexed for groups of specialists by length of time in service and by power levels of the emitters in proximity to working environments. Comparisons of health records were made between high-exposure and low-exposure groups. End points analyzed included frequency of hospitalization, disability compensation by the Veterans Administration, and, in the case of deceased individuals, cause of death. None of the end points was positively correlated with the indices of exposure. Mortality ratios--the ratios of observed-to-expected numbers of deaths--ranged from 0.85 to 1.19, and the averaged mortality ratio was close to the null value of unity. The data on hospital admissions, which were classified by disease, showed that the high-exposure group did not exhibit significantly higher admission rates than those of the low-exposure group. Rates and amounts of disability compensation did not differ between the two groups.

Wright, W.E., Peters, J.M., and Mack, T.M. (1982). Leukaemia in workers exposed to electrical and magnetic fields. *Lancet (Nov 20):* 1160-1161. [E-2]

A cancer registry in the county of Los Angeles was researched for numbers of white men during the period 1972-79 that were occupationally exposed to electrical and magnetic fields, and that carried a diagnosis of leukemia of any type. Twelve occupational specialties were represented: electronic technicians, telegraph operators, electricians, power linemen, telephone linemen, TV and radio repairmen, power-station operators, welders and flame cutters, movie projectionists, electrical engineers, and railway conductors and motormen. Proportional incidence ratios (PIRs) were calculated in which the normalized frequencies of leukemic diseases in the county-wide population were set to 100. Then the numbers of electrically occupied men were determined for three diagnostic categories: acute myelogenous leukemia ($n = 22$), acute leukemia ($n = 23$), and all forms of leukemia ($n = 35$). The respective PIRs when data on all 12 groups were pooled were 207, 173, and 129, which indicate percentage increases of 107%, 73%, and 29% above total-county base rates. The PIRs for acute leukemia and acute myelogenous leukemia, but not for all forms of leukemia, are statistically reliable (both *P*s <.05). Analyzed by specialty, power and telephone linemen were the only occupational groups among the 12 with reliable PIRs, which exceeded 550 for both forms of acute leukemia (*P*s <.05). If the data on linemen are removed from the analysis, the *P* values for PIRs of the remaining ten specialties fall to chance levels, whether pooled or considered independently. Interpretive caution was counseled by the authors because of very small samples (there were only two linemen in each of four comparisons), and because of the high probability of known carcinogens in their working environments.

Lester, J.R., and Moore D.F., (1982a). Cancer incidence and electromagnetic radiation. *J. Bioelectricity, 1:* 59-76. [E-3]

Attempts were made to correlate cancer morbidity and mortality in the city of Wichita, Kansas, with exposure of residents to radars of a nearby U.S. Air Force base and a commercial airport. Data on cancer morbidity were obtained on Wichita residents from records in city hospitals for the period 1975-1977. Mortality data on the Wichita general population were obtained from the Kansas Bureau of Registration and Health Statistics. The authors made analytical projections of the extent to which terrain between radar sources and target tracts shielded residents from the presumed radar fields. Morbidity was found to be correlated reliably with residential tracts at higher (unshielded) elevations ($P < .05$), but mortality was not. Corroboration of the analytical estimates of field strengths by physical measurements was not made, which severely limits the validity of the findings.

Lester, J.R., and Moore, D.F. 1982b). Cancer mortality and air force bases. *J. Bioelectricity, 1:* 77-82. [E-4]

The authors compared incidence of cancer mortality in counties both proximal to and remote from U.S. Air Force bases. Matched for population and paired within states, 92 proximal counties and an equal number of remote counties were surveyed. Mortality data during the period 1950-1969 were obtained from DHEW's Atlas of Cancer Mortality for U.S. counties. Statistically reliable increases in the incidence of death by cancer were reported in proximal counties for men ($P < .04$) and for women ($P < .02$). The authors speculate that exposure to electromagnetic radiations by Air Force radars was responsible for differences. The authors mention noise as a potentially contributing environmental contaminant, to which should be added engine exhaust and aviation fuel, which routinely is dumped by aircraft before landing. Not mentioned by the authors is whether remote counties serving as controls were screened for proximity to Naval or Coast Guard air bases, or to commercial airports. If remote counties were situated in proximity to other air facilities with radar, the validity of the report would be severely limited.

Vagero, D. and Olin, R. (1983). Incidence of cancer in the electric industry: Using the new Swedish cancer environment registry as a screening instrument. *Brit. J. Indust. Med., 40:* 188-192. [E-5]

The incidence of cancer was tabulated for workers that were employed in Sweden's electrical and electronic industries between 1961 and 1973. Among 54,624 men and 18,478 women in the surveyed population, 1,855 and 1,009 respective cases of cancer were reported. Of 2,108,952 men and 923,723 women in the general population, the respective frequencies of cancer were 82,750 and 51,939. Compared with the general working population, some malignancies were more frequent among the electrically employed workers. For example, cancer of the pharynx and respiratory system was cited as reliably more frequent ($P < .02$). However, overall totals of tumors and humoral malignancies were *higher* among members of the general (control) population. The respective percentages of general-population men and women with malignancies were 3.92% and 5.62%; of electrical workers, 3.40% and 5.46%. Whether an age-, sex-, or class-factor reverses the general trend of fewer malignancies among electrical workers is not clear in the report. Also complicating interpretation of the study's validity are a) neither individuals nor groups of workers were indexed for exposure; and b) other carcinogens were present in the working environments (i.e., organic solvents, acids, metallic fumes, and polychlorinated compounds).

Coleman M., Bell, J., and Skeet, R. (1983). Leukemia incidence in electrical workers. *Lancet (April 30):* 982-983. [E-6]

The incidence of malignancies was tabulated for an unspecified number of men (15-74 years of age) that were employed as electrical workers in southeast England during the period 1961-1979.

From the South Thames Cancer Registry, 125,887 cases of malignancies (tumors and humoral) were identified. Proportional registration ratios (PRRs) were calculated in which the PRR of the total Registry population was normalized to 100. The PRR for the incidence of acute lymphoid leukemia in fitters and electronic engineers was 369; for chronic lymphoid leukemia in electrical equipment assemblers, 508; and for chronic myeloid leukemia in radio-telegraph operators, 650 (all Ps <.05). Without specifying numbers, the authors cautioned that sample sizes of all three groups were small, and that there was no indexing of exposures for individuals or groups.

Hicks, N. Zack, M., Caldwell, G.G., Fernbach, D.J., and Falletta, J.M. (1984). Childhood cancer and occupational radiation exposure in parents. *Cancer, 53:* 1637-1643. [E-7]

The incidence of cancer in offspring was examined in consequence of paternal occupational exposure to radiation (exposures to ionizing and non-ionizing exposures were involved but were not differentiated). Health records from the Hematology-Oncology Services of the Houston, Texas, Children's Hospital were observed for frequency of malignancies during the period March 1976-December 1977. Children with cancer numbered 296; a control group of 283 children without cancer was sampled from records in the same clinic for the same period. Paternal occupations were categorized in terms of highly likely vs. unlikely exposure to radiation. The incidence of cancer in children was not correlated with their father's exposure classification.

Pearce N.E., Sheppard, R.A., Howard, J.K., Fraser, J., and Lilley, B.M. (1985). Leukaemia in electrical workers in New Zealand. *Lancet (April 6):* pp. 811-812. [E-8]

The authors report a study of 546 adult, male, leukemia patients in New Zealand with an occupational history of exposure to electric and magnetic fields. Case subjects were drawn from the New Zealand Cancer registry as was a control group of 2,184 men with a diagnosis of leukemia. Controls were not occupationally exposed to EM fields. Overall, the proportional incidence of leukemia was higher in occupationally exposed men as compared with occupationally unexposed men; however, the difference is of marginal reliability (*P* ˜.06). Among some subsets of electrical workers, a higher incidence of leukemia was cited, with *P* values near .02 (electronic assemblers) and .01 (radio and television repairmen). The associations between field exposures and leukemia are suspect on two grounds: a) the *P* value of the overall analysis is of doubtful statistical reliability; and b) the authors note the possibility of confounding exposures to carcinogenic compounds in the occupational environments.

Milham, S. Jr. (1985a). Silent keys: Leukemia mortality in amateur radio operators. *Lancet (April 6):* 812. [E-9]

Cause of death was tabulated for male members of the American Radio Relay League (ARRL) in Washington (N = 280) and California

(N = 1411) between 1971 and 1983. An increased incidence of leukemia of all types was observed among these amateur radio operators when their mortality statistics were compared with those of the general population (proportional mortality rate = 191/100; *P* <.01). That the occupation of the radio amateurs may be unrelated to the finding of increased mortality is indicated by data from the Washington sample: 35 percent of the membership was employed in settings that involved exposure to EM fields, yet no difference in mortality was observed between these deceased members and deceased members not so employed.

Milham, S. Jr. (1985b). Mortality in workers exposed to electromagnetic fields. *Environ. Health Perspect. 62:* 297-300. [E-10]

This report updates the author's previous report in the *New England J. Med. (Vol. 307,* p. 249, 1982). Based on data in a Washington State registry, mortality of 486,000 male workers was tabulated for the period 1950-1982. Nine occupational specialties involving exposure to electromagnetic fields were identified: electrical and electronic technicians, radio and telegraph operators, power and telephone linemen, radio and television repairmen, power-station operators, electricians, motion-picture projectionists, aluminum workers, and welders and flamecutters. Proportional mortality ratios (PMRs) were calculated from data in the registry. For all forms of leukemia among electrically employed workers, the PMR was 136/100 (*P* <.01). Other malignancies that were correlated with occupational exposure to EM fields were neoplasms of the pancreas, lung, and brain (PMRs ranged from 114/100 to 123/100; all Ps <.05). The author noted that other carcinogens were present in the working environments.

Calle, E.E., and Savitz, D.A. (1985). Leukemia in occupational groups with presumed exposure to electrical and magnetic fields. *New England J. Med., 313:* 1476-1477. [E-11]

Mortality from leukemia between 1963 and 1978 was tabulated from records in Wisconsin of caucasian men employed as electrical engineers, electronic technicians, radio and telegraph operators, electricians, power and telephone linemen, television and radio repairmen, motion-picture projectionists, street-car and subway motormen, power-station operators, and welders and flamecutters. The authors reported that a reliable increase in the overall incidence of leukemia was not found among workers in these occupations. However, the authors state that leukemia was significantly more prevalent among engineers and among radio and telegraph operators (both Ps <.05).

U.S. Senate Committee on Commerce, Science, and Transportation (1979). *Microwave Irradiation of the U.S. Embassy in Moscow.* Govt. Printing Office: Washington, pp. 26. [cf. Lilienfeld, A.M., Tonascia, J., Tonascia, S., Libauer, C.A., and Cauthen, G.M. (1978). *Foreign Service Health Study--Evaluation of Health Status of Foreign Service and other Employees from Selected Eastern*

European Posts. Final Report, Contract No. 6025-619073 (NTIS PB-288163). Dept. of State: Washington, pp. 436.] [E-12]

The U.S. Embassy in Moscow has been the intermittent target of Soviet launched microwaves for several decades. During the late 1970s, amid media speculation that embassy staff and dependents were afflicted with an unusually high incidence of disease, including malignancies, officials of the Department of State contracted with Dr. A.J. Lilienfeld of the Johns Hopkins University to perform a retrospective epidemiological study. A total of 4,388 employees that worked in nine Eastern European embassies during the period 1943-1976 was surveyed, as were 8,283 dependents. Of these totals, approximately 1,800 staff with 3,000 dependents were associated with the Moscow Embassy, the remainders having been associated with the other eight posts. Measurements of microwave fields were made external to and within the Embassy. The highest intensities (usually less than 5 microwatts per square centimeter--5 $\mu W/cm^2$--and with a maximal value near 18 $\mu W/cm^2$) were measured on the roof of the Embassy. Successful contact was made with 95 percent of the staff, but only 52 percent completed an extensive questionnaire about status of health and that of dependents. Comparisons of morbidity and mortality among the nine Eastern European posts, and between them and the U.S. population as a whole, revealed no indications of adverse effects on health of Moscow-based personnel or their dependents. No correlation was observed between field intensity and frequency of illness in employees that were stationed at different levels within the Embassy building.

In vivo *Studies: Laboratory Research on Live Animals*

Manikowska, E., Luciani, J.M., Servantie, B., Czerski, P., Obrenovitch, J., and Stahl, A. (1979). Effects of 9.4-GHz microwave exposure on meiosis in mice. *Experientia 35:* 388-390. [A-1]

Male mice were exposed to 9.4-GHz pulsed microwaves during 10, daily, 1-h sessions at power densities of 100, 500, 1,000, and 10,000 $\mu W/cm^2$. Pulses at 0.5-s widths recurred at 1000 pulses per second (pps). Four mice were exposed at each power density. Seven mice served as controls, but the control condition (use of corporal restraint, sham exposure, no treatment, etc.) was not specified. Spermatogensis was studied after the last exposure. Relative to controls, the incidence of chromosomal translocations --the exchange of segments between unpaired sets of chromosomes--was significantly higher in microwave-exposed animals ($P < .01$). Respective means of translocations at 0, 100, 500, 1,000, and 10,000 $\mu W/cm^2$ were 3, 6, 3, 10, and 9. The authors also report an increased incidence of chromosomes remaining univalent (failing to achieve a normal pairing) in the M1 phase.

Szmigielski, A., Szudzinski, A., Pietraszek, A., Bielec, M., Janiak, M., and Wrembel, J.K. (1982). Accelerated development of spontaneous and benzopyrene-induced skin cancer in mice exposed to 2450 MHz microwave radiation. *Bioelectromagnetics 3:* 179-191. [A-2]

Mice with a high incidence of spontaneously developing mammary cancer, and other mice, the skin of which repeatedly was painted with 3,4-benzopyrene (BP), were sham irradiated or irradiated daily by continuous-wave microwaves at 5,000 $\mu W/cm^2$ (2-3 W/kg) or 15,000 $\mu W/cm^2$ (6-8 W/kg). (Sham irradiation is a procedure in which controls are treated the same as experimental animals, but they are not exposed to radiation.) The BP was painted on a 1 x 1-cm area of depilated skin every second day for five months. Sample Ns of 40 were used in most experiments. The mammary-cancer-prone mice were irradiated from the 6th week to the 12th month of age. The BP-painted mice were irradiated either prior to (1 or 3 months) or simultaneously with a daily BP treatment. Microwave irradiation accelerated development of cancers in the both groups of mice. Strong dose-response relations were observed. *P* values below .05 were generated by most of the control-irradiated differences. Lung cancer was induced in a third group of mice by intravenous injection of sarcoma cells; a higher incidence of lung cancer was observed in microwave-irradiated mice than in sham-irradiated controls, which indicates a reduction in natural anti-neoplastic resistance. In a fourth, special group of control mice, stress induced by chronic confinement and isolation also was found to produce accelerated development of malignancies. In none of the groups was evidence found of primary, microwave-induced carcinogenesis, but the data strongly indicate that the prolonged bouts of irradiation promoted (accelerated growth of) malignancies. The authors concluded that microwave irradiation at the noted intensities and durations can act as a source of non-specific stress.

Saunders, R.D., Darby, S.C., and Kowalczuk, C.I. (1983). Dominant lethal studies in male mice after exposure to 2.45 GHz microwave radiation. *Mutation Res., 117:* 345-356. [A-3]

Male mice (n = 24) were anesthetized, partially inserted in a waveguide, the posterior half of their bodies then being subjected to irradiation by 2.45-GHz microwaves for 30 min. at an SAR of 45 W/kg. Eighteen mice served as sham-exposed controls. Except for frequency, field parameters were not specified. Mating with pairs of hybrid mice followed, 8 to 10 weeks after irradiation. Fourteen days after mating, uterine contents were examined. Post-implantation survival of embryos was not adversely affected, but rates of fertilization and implantation were (Ps <.05). The reduced rates were correlated with the extent to which temperatures were elevated in irradiated mice; that is, hyperthermia induced by microwave irradiation resulted in attenuation of viable sperm.

Manikowska-Czerska, E., Czerski, P., and Leach, W.M. (1985). Effects of 2.45 GHz microwaves on meiotic chromosomes of male CBA/CAY mice. *J. Heredity, 76:* 71-73. [A-4]

Male mice in groups of 3 to 11 were irradiated by 2.45-GHz, continuous-wave microwaves at whole body SARs of 0, 0.05, 0.5, 5, 10, and 20 W/kg during 12, daily, 30-min. sessions. Effects on meiosis were studied. An increase in translocations of chromosomes was observed in the microwave-irradiated mice as compared with controls ($P < .001$). There was a non-linear dose-response relation. The validity of the findings with respect to microwave irradiation as the sole causal agent is uncertain because of the severe corporal restraint imposed on animals during radiation treatments.

Kunz, L.L., Johnson, R.B., Thompson. D, Crawley, J., Chou, C.-K., and Guy, A.W. (1985). *Effects of long-term low-level radiofrequency radiation exposure on rats.* USAF School of Aerospace Medicine Report No. USAFSAM-TR-85-11. [A-5]

Rats were exposed over life spans approximating 2.5 years to 2.45-GHz, pulsed microwaves. Irradiation of individual animals occurred in waveguides that were fed with microwave energy at a fixed power level. Whole-body-averaged SARs ranged downward from 0.4 to 0.15 W/kg as the animals matured and gained in body mass over time. Ten-microsecond pulses recurred at 800 pulses per second; in addition, square-wave modulation at a recurrence rate of eight waves per second was imposed. One-hundred rats were irradiated, and an equal number served as sham-irradiated controls. Survival times and most histopathological end points did not differ reliably between experimental and control animals. However, the total number of animals with primary, lethal malignancies, all sites and organs taken into account, was significantly higher in irradiated rats ($n = 18$) than in controls ($n = 5$). Even by conservative statistical test, the nearly fourfold difference is highly reliable ($P < .005$).

In vitro *Studies: Experiments on Isolated Cells and Tissues*

Swicord, M.L., Edwards, G.S., Sagripanti, J.L., and Davis, C.C. (1983). Chain-length-dependent microwave absorption of DNA. *Biopolymers 22:* 2513-2516. [I-1]

The end point of this study was relative absorption of microwave energy by DNA chains as a function of wavelength. Frequencies of fields imposed in a waveguide ranged from 8- to 12-GHz. Except for frequency, field parameters were not reported. DNA samples from *E. coli* were treated with an endonuclease for various periods of time. Maximal mean lengthening of DNA chains was observed after 85 min. of enzyme action. Absorption of microwave energy increased with time of incubation, also reaching a maximum at 85 min. Absorption coefficients maximized at 11-GHz, the relative absorption value increasing by 70 percent. (Unknown is whether statistical tests were performed or whether the increase reported is statistically reliable.) The authors concluded that microwave absorption by DNA is chain-length dependent, and that further proof of this relation will require experimentation on DNA molecules with known chain lengths.

Balcer-Kubiczek, E.K., and Harrison, G.H. (1985). Evidence for microwave carcinogenesis *in vitro*. *Carcinogenesis, 6:* 859-864. [I-2]

The authors report effects of 24 hours of irradiation of mouse embryoblasts by pulsed, 2.45-GHz microwaves at an SAR of 4.4 W/kg. The pulse width was 83 microseconds and the recurrence rate was 120 pulses per second. Microwaves alone or in combination with benzopyrene (BP) or X-irradiation (1.5 to 6.0 Greys) were assessed for carcinogenic potential. Survival and malignant transformation of mouse-embryo fibroblasts in culture were the end points. A clonogenic assay of survival showed that microwave irradiation resulted in a constant level of lethality in embryos, in addition to the damage wrought by X-rays and BP. Microwave irradiation did not augment the rate of cell transformation by BP or X-rays. However, microwave irradiation enhanced the rate of transformation when cells were treated with a non-cytotoxic, non-transforming dose of a tumor promoter, 12-O-tetradecanoylphorbol-13-acetate. This result indicates that microwaves might cause latent transformational damage that is manifest only in the presence of a tumor promoter. The findings were not subjected to statistical analyses.

Goodman, R., and Henderson, A.S. (1986). Sine waves enhance cellular transcription. *Bioelectromagnetics, 7:* 23-29. [I-3]

Excised salivary glands from larvae of the housefly, *Sciara coprophila*, were irradiated for 15-60 min. by a low-frequency magnetic field at 72, 222, or 4,000 Hz at respective magnetic field densities of 1.15, 0.37, and 0.018 milliteslas (mT). Glands also were exposed to single, repetitive pulses (380-microsecond pulses at 72 pulses per second) for 60 min. in culture dishes in a medium of 3H-uridine (all sample ns = 100). Transcription (construction of RNA molecules from DNA) was studied by autoradiography of 3H-uridine-labeled RNA attached to chromosomes and also by analysis of radiolabeled RNA with sucrose-density-gradient centrifugation. An increased rate of transcription was observed. The labelled RNA was in the 6-10s and 20-25s range. Most of the RNA transcribed was mRNA. Profiles of transcription showed that 72-Hz sine waves and pulsed fields at 72 pulses per second produced similar outcomes. Under exposure to the sinusoidal field, there was a proportional increase in rate of transcription with time of exposure (15-45 min). The response to the pulsed field was bimodal; that is, smaller quantities of labelled RNA were incorporated at 30 min than at 15 or 45 min. of exposure. Increasing the frequency of the sine-wave field resulted in slower activation of transcription. Whether the field increased normal transcription or activated transcription of a previously inactive gene was not determined. Statistical analyses were not performed.

DISCUSSION

Retrospective Epidemiological Studies

Statistically reliable evidence of associations between EM fields and adverse health effects was cited in 8 of the 12 epidemiological reports (Lester & Moore, 1982 a,b; Coleman et al., 1983; Hicks et al., 1984; Milham, 1985 a,b; Pearce et al., 1985; Wright et al., 1982; Vagero & Olin, 1983). Authors of six of the eight papers cite statistical evidence of a correlation between exposure to RF fields and development of malignant disease (Lester & Moore, Milham (both papers), Wright et al., Coleman et al., and Pearce et al.), but on scrutiny of the findings, consistency is found lacking between the exposure variable and pathophysiological end points. That is, malignancies of a given type are believed by most pathologists to be causally linked to specific carcinogens, but the malignancies cited by the authors differ markedly. For example, Milham reported an increased incidence of humoral (leukemic) malignancies. Lester and Moore cited an increased incidence of malignant tumors of bone, connective tissue, skin, and breast. And Wright et al. reported an increased incidence of acute myelogenous leukemia, which was not observed in the Pearce et al. study.

As another example of inconsistency, telephone and telegraph linemen were cited by Wright et al. as having a very high incidence of acute leukemia and acute myelogenous leukemia. In contrast, the linemen in the study of Pearce et al. had a very low incidence of these disorders.

A caveat cited in nearly all reports with positive findings was the presence or potential presence of carcinogenic compounds in the occupational environments. Confounding of health measures by established or suspected carcinogens presents an insurmountable interpretive problem that could be resolved only by parcelling the effects of these chemical and physical agents from the authors' data. Unless data on independently measured quantities of carcinogens and electromagnetic fields are available for a given occupational setting, it is not possible to analyze the data from several settings and assign probability of causal connections between specific agents and specific malignancies.

The first of two reports by Lester and Moore (1982a) is severely limited by the absence of physical measurements to substantiate their thesis that airport radars are the source of biological insult to residents of Wichita that live at higher ("unshielded") elevations. The same criticism can be leveled at their second report (1982b), in which they attempt to link U.S. Air Force radars with insult to human health. In the second report, they also neglect consideration of many military-airbase and civil-airport radars that may be proximal to the counties in which control counts of disease incidence were made. Lester and Moore do caution the reader that noise pollution could be a confounding factor. A causal relation between noise stress and development of cancer is relatively well established.

A positive association between radiation and malignant disease was reported by Hicks et al. and by Vagero and Olin. The former paper is based primarily on ionizing radiations, and the authors provide no data on the effects of RF radiation as such. Vagero and Olin reported an increased incidence of pharyngeal and respiratory-system cancers in workers employed in the electronics and electrical manufacturing industries. Physical measurements of fields in the industrial settings were not measured by Vagero and Olin. They, too, note the presence of air-born carcinogens in the working environments.

From the epidemiological reports, the following conclusions may be drawn:

(1) When the 12 studies are considered as a whole, there is no consistently reported association between RF radiation and a *specific* disease entity in exposed workers. This generalization holds for electrically employed workers whether all occupational specialties are pooled or are considered independently. How does one account for the sizeable correlations that often are cited between one or more of the several leukemias and occupations that are presumed to expose workers to RF fields? It is possible that these correlations are statistical artifacts. On the other hand, according to several authors, these occupations involved combined exposures: to RF fields and to one or more of any number of established carcinogens. Thus it is also possible, in any of the studies giving rise to a positive finding, that an RF field promoted the action of a specific carcinogen in a specific occupational environment. If so, the lack of consistency among the epidemiological studies in the types and incidence of leukemia arose from a differing mix of carcinogen(s) and promoter in different industrial settings. One harkens here to the experimental findings of Szmigielski et al. Three different factors, genetic, chemical, and biological, were used to produce cancers of three different types in, respectively, mammaries, skin, and lungs. And mice exposed to the same microwave field, albeit at relatively high intensities, promoted the growth of all three types of cancer.

(2) Confounding factors, such as the presence or probable presence of established carcinogens in the working environments, were cited--but could not be parcelled from the data--by most authors of epidemiological reports.

(3) In several studies, the reliability of findings is limited by small and/or non-representative samples.

(4) In all reports under review, durations of exposure, intensities of fields, and other critical field and dosimetric parameters, have not been measured or estimated for individual subjects. And, except for the studies of Silverman et al. and of Lilienfeld et al., exposures were not estimated or indexed for groups.

(5) Although the 12 epidemiological studies cited herein do not exhaust the literature, they are fairly representative of the larger data base. Of interest when examined collectively is that the citation of statistically reliable correlations between exposure to RF fields and malignancies is generally associated with the less-rigorous, less-comprehensive studies. For example, the two most comprehensive studies, and the only ones in which attempts were made to relate measures of field intensities to incidence of health disorders, yielded consistently negative results on all of a large number of health-related end points (Silverman et al. and Lilienfeld et al.). In contrast, several studies based on smaller populations and lacking measures of RF fields (e.g., Pearce et al. and Wright et al.'s studies of electrical workers) yielded the strongest prima-facie evidence of ill effects.

(6) Possibly contravening the generalization that claims of hazards are inversely related to comprehensiveness of study is Milham's investigation of amateur-radio operators. In operating, typically, a 1000-watt transmitter in proximity to their homes, the amateurs and members of their families may be exposed to the strongest fields to which any sizeable segment of U.S. population is subject. If so, Milham's twin findings--high incidence of all leukemias, and lack of correlation with the amateur's occupation--are supportive of the thesis that exposure to strong fields *as such* may pose health hazards to the human being. In the absence of precise measurements of transmitter fields as incident on, in, and about the homes of the amateur-radio operator, one may only speculate that intensities exceed limits recommended by standard-setting bodies.

(7) The only studies in which there was minimal likelihood that physical or chemical carcinogens were present in working environments (again, those of Silverman et al. and Lilienfeld et al.) revealed no evidence of adverse effects on health of electromagnetically exposed populations. This observation may indicate the absence of field-induced insult, although the possibility that RF fields may complex with toxic agents cannot be ruled out. That is, RF fields alone may not affect health, but it is conceivable that such fields may unmask or exacerbate toxic properties of other agents in the working environment.

In vivo *Studies of Subhuman Animals*

The reports include two studies of microwaves irradiation and meiosis (Manikowska et al., 1979; Manikowska-Czerska et al., 1985), one study of co-carcinogenic properties of microwaves (Szmigielski et al., 1982); one study that assessed male fertility and potential mutagenic effects of microwave irradiation (Saunders et al., 1983), and one study that examined histopathological effects of near-life-long exposure to microwaves (Kunz et al., 1985). Positive findings are reported in all these papers.

Manikowska-Czerska et al. used both continuous-wave and pulsed microwaves to investigate meiotic activity in the mouse. Both studies yielded similar results: increased numbers of translocations and of univalent chromosomes in the M1 phase of the meiotic process. These findings were observed at a very low SAR (0.05 W/kg). Similar studies were performed on mice by Saunders et al. at a much higher SAR (45 W/kg). Although Saunders et al. observed impaired fertility, they found no evidence of mutagenesis in a dominant-lethal assay. The difference in outcomes may be related to a difference in end points, but reliance by Manikowski-Czerska et al. on highly confining corporal restraint of their mice resulted in experimental animals that were subjected to a potent source of physical and psychogenic stress.

Szmigielski et al. and Kunz et al. respectively reported evidence of co-carcinogenic and carcinogenic effects of long-term microwave irradiation. The experiments of Szmigielski et al. were based on higher SARs (3-8 W/kg), and highly reliable results were obtained that are consonant with the thesis of a weakening of the mouse's natural anti-neoplastic resistance. Co-carcinogenic properties of microwaves also were demonstrated. In addition, the authors found that "isolation and confinement"--a form of restraint--in the absence of irradiation was nearly as efficacious as exposures at 3 W/kg in promoting cancer. Considered together, the data of the several experiments by Szmigielski et al. may be taken as evidence that microwave fields, which are moderately intense for the mouse, are a source of non-specific stress. Such stress can accelerate growth of malignancies induced by other agents--and this promotion would result from a weakening of the organism's immune defenses and, thus, its resistance to growth of neoplasms.

The Kunz et al. study was based on relatively low, whole-body-averaged SARs. The SAR initially was 0.4 W/kg for young rats, and it progressively decreased to 0.15 W/kg) as the animals' body mass increased during 25 months of near-continuous irradiation. This study is unique in that large numbers of animals, 100 each in experimental and sham-exposed groups, were exposed during most of the normal span of the rat's life. Measurements of various histopathological end points revealed few reliable effects of irradiation, and longevity of the rats was not affected. One finding, which appropriately is labelled "provocative" by its authors, lay in frequencies of primary malignant tumors: 5 in controls, and 18 in irradiated rats. Even by conservative statistical test, the difference is highly reliable (P <.005).

In vitro Studies

Three reports were reviewed; all three were designed to shed light on mechanisms by which RF radiation might possess carcinogenic properties. In the study by Balcer-Kubiczek and Harrison, microwave irradiation of cultured fibroblasts at an SAR of 4.4 W/kg failed to augment the carcinogenic or lethal effects of x-irradiation or benzopyrene. Other data revealed co-carcinogenic properties of the microwave radiation; i.e., when combined with a tumor promoter, microwaves enhanced the rate of promotion. The finding of enhanced promotion comports with the *in vivo* studies of Szmigielski et al.

Goodman and Henderson reported that a low-frequency, sine-wave, magnetic field increased transcription activity in cells. However, it is not clear whether the enhanced transcription was due to an increase in activity of a normally active genome or to activation of normally inactive genes. Identification of these genes may be important in understanding the mutagenic or carcinogenic effect of electromagnetic irradiation.

The study of Swicord et al. showed that absorption of electromagnetic radiation might be dependent on the length of the DNA molecule, and that the absorption might be related to resonant properties of the molecules. This study is important, because it might indicate that certain structures of the genome of an organism are selectively susceptible to RF radiations.

Considered in sum, the import of the *in vitro* studies lies decisively in the quest rather than in the ascertainment of mechanisms--specifically, in the search to identify modes of athermal interactions. The data of the three studies and of many other *in vitro* studies that have been reported in the literature do not speak directly to the question of human health. This is because irradiation of isolated cells or tissues removes them from the homeostatic buffer of the intact organism. The value of such studies will lie in their integration with and explanation of field-induced phenomena the arise in the intact organism. Only recently has there been a gathering consensus among experts that athermal effects--beyond those of electric shock--probably exist and possibly portend adverse consequences.

INTEGRATION AND EXTRAPOLATION OF DATA

Caveats on Epidemiological Data

Epidemiological studies, by their nature, can not demonstrate a cause-effect relation. Whatever the toxic variable of concern in an industrial or general-population setting, the intrusion of uncontrolled factors is highly probable. In most of the 12 retrospective epidemiological reports under review, their authors noted that toxic or carcinogenic agents may have been or were present in working or mundane environments. The prime question that drove 11 of the 12 studies--are RF fields carcinogenic or promoters of malignant disease?--was often answered by the citing of reliable correlations. But each correlation rests on the possibility that toxic chemicals, heavy metals, ionizing radiations, excessive noise, or other stresses were the sources of biological insult. Not to be ruled out, however, is the possibility of "complexing," i.e., that RF fields, if benign in isolation, might exacerbate the ill effects of other toxic agents.

The value of an epidemiological study lies in the generation of a plausible hypothesis. The value of a set of epidemiological studies with a common focus lies in the extent to which a commonality of findings lends credence to the hypothesis. But only in the laboratory can the controls be implemented by which to exclude extraneous sources of variation and, thus, to test the hypothesis and establish the probability of a cause-effect relation.

The first question to be addressed in this review is whether a commonality exists in the outcomes of the epidemiological studies. The answer is both yes and no. Yes, in the general sense that authors of several studies report a heightened incidence of malignancies in workers exposed to RF fields. No, in the specific sense that disagreement frequently exists with respect to a given malignancy or to a given occupational specialty. The disagreements dilute but do not dismiss the cogency of submitting the hypothesis to experimental test.

The second question addressed in this review is whether the *in vivo* and *in vitro* experimental findings are supportive of a hypothesized connection between RF irradiation and malignant disease. The answer is a highly qualified yes. The *in vivo* experiments assigned for review are mixed in their degree of rigor and in their meeting additional criteria that are needed to establish causal specificity: ecological validity, response equivalence, and independence of confirmation. By rigor is meant the extent to which the variable of interest--RF radiation--is the only factor that separates experimental and control treatments. By ecological validity is meant the extent to which the conditions of human and infrahuman exposure to some agent are parallel. By response equivalence is meant the extent to which the responsiveness of the animal model emulates that of the human being. And by independence of confirmation is meant replication of a finding by an investigator not associated with the conduct of an earlier, duplicated experiment.

The methodology giving rise to the findings of Manikowska-Czerska and colleagues exemplify the problem of achieving rigor because of the authors' use of severe corporal restraint during irradiation of their mice. To maintain a consistent exposure geometry in a microwave field, which is necessary to maintain a constant level of energy dosing (SAR), the authors placed each of their mice in a tightly fitting plastic tube. Other investigators (see., e.g, Szmigielski et al.) have found that even loosely confining an animal to restrict movement can introduce severe stress. More, the intensity of stress when restraint is combined with normally tolerable levels of microwave irradiation is greatly magnified, and has resulted in severe insult and lethality.

Achievement of ecological validity in experiments involving RF radiation of animal models is extremely difficult for several reasons. Little is known, for example, about the typical exposure history of individual workers or groups of workers in any given occupational setting. And even if field parameters and